

LEVEL

12

AD

AD A106198

TECHNICAL REPORT ARBRL-TR-02361

A LINK BETWEEN SHAPED CHARGE  
PERFORMANCE AND DESIGN.

Ralph E. Shear  
Frederick S. Brundick  
John T. Harrison

September 1981

DTIC  
SELECTED  
OCT 27 1981

A



US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND  
BALLISTIC RESEARCH LABORATORY  
ABERDEEN PROVING GROUND, MARYLAND

Approved for public release; distribution unlimited.

81 10 27 277

COPY

Destroy this report when it is no longer needed.  
Do not return it to the originator.

Secondary distribution of this report by originating  
or sponsoring activity is prohibited.

Additional copies of this report may be obtained  
from the National Technical Information Service,  
U.S. Department of Commerce, Springfield, Virginia  
22151.

The findings in this report are not to be construed as  
an official Department of the Army position, unless  
so designated by other authorized documents.

*The use of trade names or manufacturers' names in this report  
does not constitute indorsement of any commercial product.*

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER TECHNICAL REPORT ARBRL-TR-02361	2. GOVT ACCESSION NO. AD-A106198	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) A LINK BETWEEN SHAPED CHARGE PERFORMANCE AND DESIGN		5. TYPE OF REPORT & PERIOD COVERED Final
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Ralph E. Shear Frederick S. Brundick John T. Harrison		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Ballistic Research Laboratory ATTN: ORDAR-BLV Aberdeen Proving Ground, MD 21005		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 1L161101A91A
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Armament Research & Development Command US Army Ballistic Research Laboratory ATTN: ORDAR-BL Aberdeen Proving Ground, MD 21005		12. REPORT DATE SEPTEMBER 1981
		13. NUMBER OF PAGES 27
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		16. DECLASSIFICATION/DOWNGRADING SCHEDULE
17. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
18. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
19. SUPPLEMENTARY NOTES		
20. KEY WORDS (Continue on reverse side if necessary and identify by block number) Shaped Charge Jet Break-up Time Jet Parameters		
21. ABSTRACT (Continue on reverse side if necessary and identify by block number) It is illustrated that the penetration performance of a shaped charge determines "best" values of parameters in the DiPersio, Simon, and Merendino theory of penetration by shaped-charge jets and that it is possible to relate these penetration parameters to design parameters such as cone angle and liner thickness.		

DD FORM 1 JAN 79 1473

EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

## TABLE OF CONTENTS

	Page
I. INTRODUCTION	5
II. DETERMINATION OF $U_{MIN}$ AND $t$	6
III. AN EXAMPLE	7
IV. VIRTUAL ORIGIN APPROXIMATION	8
V. DETERMINATION OF THE ENERGY CONSTANT	13
VI. SUMMARY	20
ACKNOWLEDGEMENTS	21

Accession For	
NTIS GRA&I	<input checked="" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
For	5
Distribution/	6
Availability Codes	7
or	8
A	13

## LIST OF TABLES

### Table

1	Some Calculated and Observed Jet Data for the 3.81 cm Copper Liner Shaped Charge	11
2	Experimental and BASC-Code Generated Values of Jet Tip Velocity for Selected 3.81 cm Aluminum and Copper Liners	12

## LIST OF FIGURES

### Figure

1	Calculated and Experimental Penetration Depth vs Standoff Distance from Virtual Origin for the BRL Precision Shaped Charge	9
2	Penetration Depth vs Virtual Standoff Distance for the 3.81 cm, Cu, Conical Liner, Cone Angle = 20°	14
3	Penetration Depth vs Virtual Standoff Distance for the 3.81 cm, Cu, Conical Liner, Cone Angle = 40°	15
4	Penetration Depth vs Virtual Standoff Distance for the 3.81 cm, Cu, Conical Liner, Cone Angle = 60°	16
5	Penetration Depth vs Virtual Standoff Distance for the 3.81 cm, Cu, Conical Liner, Cone Angle = 90°	17
6	Calculated Virtual Origin vs Cone Angle	18
7	Calculated $U_{Min}$ vs Cone Angle	19
	DISTRIBUTION LIST	23

## I. INTRODUCTION

DiPersio, Simon, and Merendino<sup>1</sup> presented equations to determine the penetration depth and hole volume associated with a shaped charge jet impacting a given target. In particular, given jet and target material densities,  $\rho_j$  and  $\rho_t$ , jet break-up time,  $t_1$ , initial jet tip velocity,  $V_j^0$ , minimum penetration velocity\*,  $U_{min}$ , the penetration depth, as a function of the virtual stand-off distance,  $Z_0$ , can be computed. In addition, if given average jet diameter,  $d_j$ , and an energy constant,  $C$ , DiPersio, et al provide equations which enables one to calculate the hole volume associated with the penetrating jet. DiPersio, et al obtained values of  $t_1$ ,  $U_{min}$ , and  $V_j^0$  from experimental measurements for a precision shaped charge, with a  $42^\circ$  conical liner, and calculated the total penetration depth as a function of stand-off distance for this particular charge. They obtained favorable agreement with experimental measurements of penetration depth at various stand-off distances where the stand-off distance is the distance from the base of the liner to the target.

A question raised by one of the authors (J.T.H.) was, "Under what conditions does the experimental penetration depth - stand-off data and hole volume - stand-off data determine or infer the values of  $C$ ,  $U_{min}$ , and  $t_1$ ?", i.e., the parameters utilized in the DiPersio, Simon, and Merendino (DSM) equations.

A partial answer to this question was given earlier by Majerus and Scott<sup>2</sup>, who utilized a modified form of the DSM equations and investigated the round-to-round variability of  $C$  and  $U_{min}$ . Majerus and Scott provided a computational method of determining  $C$  and  $U_{min}$  from experimental penetration and hole volume - stand-off data. In their method, they required, in addition to target and material properties, location of virtual origin, jet break-up time,  $t_1$ , jet tip velocity, jet diameter, etc.

<sup>1</sup> R. DiPersio, J. Simon, and A. Merendino, "Penetration of Shaped Charge Jets into Metallic Targets," BRL R-1296, September 1965, (UNCLASSIFIED).  
\* (AD #476717)

Also called an interaction parameter; see Reference 2.

<sup>2</sup> J. Majerus and B. Scott, "CUMIN: A Computer Code for Determining Certain Jet/Target Parameters from Experimental Data," ARBRL-TR-02129, December 1978, (UNCLASSIFIED). (AD #B035331L)

In the following, we show that functions of the DSM parameters,  $t_1$ ,  $U_{\min}$ , and  $C$ , can be determined from experimental penetration and hole volume-stand-off data or, in fact, from desired penetration performance data. These functions, together with specification of  $V_j^0$  and jet diameter  $d_j$  yield estimates of  $t_1$ ,  $U_{\min}$ , and  $C$ . Since  $V_j^0$  and  $d_j$  are readily determined from the BASC<sup>3</sup> code and only require knowledge of material densities, some explosive properties, liner thickness,  $\epsilon$ , and cone angle,  $\alpha$ , the methodology provided herein enables one to calculate these DSM parameters without additional experimentation. Such a procedure may be useful in shaped charge design problems.

## II. DETERMINATION OF $U_{\min}$ AND $t$

Letting  $x = V_j^0 t_1$ , and  $y = U_{\min} t_1$  then the total penetration of the jet into the target is given by\*

$$P_T = Z_0 [ \{ x/(1+\gamma)y \}^{1/\gamma} - 1 ] \quad (1)$$

whenever

$$0 \leq Z_0 \leq (1+\gamma)y [(1+\gamma)y/x]^{1/\gamma} \quad (2)$$

where  $\gamma = \sqrt{\rho_t/\rho_j}$ , or by

$$P_T = [(1+\gamma)x^{1/(\gamma+1)}Z_0^{\gamma/(1+\gamma)} - \sqrt{(1+\gamma)yx^{1/(\gamma+1)}Z_0^{\gamma/(1+\gamma)}}] / \gamma - Z_0 \quad (3)$$

whenever

$$(1+\gamma)y[(1+\gamma)y/x]^{1/\gamma} \leq Z_0 \leq x \quad (4)$$

or

$$P_T = [x - \sqrt{y(x+\gamma Z_0)}] / \gamma \quad (5)$$

whenever

$$x \leq Z_0 \leq x(x/y - 1) / \gamma \quad (6)$$

<sup>3</sup> J. Harrison, "Improved Analytical Shaped Charge Code: BASC", ARBRL-TR- 02300, March 1981. (AD #A100275)

\* Equations (22)-(25) of reference 2.

Equations (1) - (6) enable one to calculate the total jet penetration as a function of stand-off from the virtual origin,  $Z_0$ , whenever  $x$  and  $y$  are known. We note from (2), (4), and (6) that the boundary of each region is also a function of  $x$  and  $y$ . Thus if  $x^*$  and  $y^*$  are known values of  $x$  and  $y$ , then this specification determines a partition such that given a value of  $Z_0$  one can determine the corresponding value of  $P_T$ .

If we are given  $\{ (P_{T,i}, Z_{0,i}) \}$  for  $i = 1, \dots, N$  and where

$P_{T,i}$  is either the observed value of  $P_T$  at  $Z_0 = Z_{0,i}$  or is the desired performance at  $Z_0 = Z_{0,i}$  then we can obtain "best" values of  $x$  and  $y$ , i.e.,  $x^*, y^*$  as follows. We note that the boundary between each region of validity for equations (1), (3), and (5) is a function of  $x$  and  $y$ , thus for each value of  $x$  and  $y$ , we can compute the value of  $P_T = f(x, y, Z_0)$  for any given value of  $Z_0$ . If not, then the values of  $x$  and  $y$  lie outside the feasible region. We let

$$H(x, y) = \sum_{i=1}^N [ P_{T,i}(Z_{0,i}) - f(x, y, Z_{0,i}) ]^2 \quad (7)$$

and we determine  $x^*, y^*$  such that

$$H(x^*, y^*) \leq H(x, y) \text{ for all } x, y. \quad (8)$$

If  $V_j^0$  is known, then  $t_1$  and  $U_{\min}$  follow from the definition of  $x$  and  $y$ .

### III. AN EXAMPLE

Experimental data for the BRL Standard-Shaped charge are provided by DSM. Included within this data are total penetration vs. stand-off, jet break-up time, initial jet tip velocity, and minimum penetration velocity  $U_{\min}$ . We have utilized the penetration stand-off data for stand-off  $\min$  distances through 20 cone diameters (we did not use the penetration depth at 25 cone diameters) in equation (7), i.e., we obtained the solution  $x^*, y^*$  from obtaining

$$\min_{x, y} \sum_{i=1}^N [ P_{T,i}(Z_{0,i}) - f(x, y, Z_{0,i}) ]^2 \quad (9)$$

from which we found

$$\begin{aligned} x^* &= 85.905 \text{ cm} \\ y^* &= 11.41 \text{ cm} \end{aligned} \quad (10)$$

DSM reported that  $V_j^0 = 0.830 \text{ cm}/\mu\text{sec}$  thus since  $x^* = V_j t_1^*$  and  $y^* = U_{\min} t_1^*$  we have

$$\begin{aligned} t_1^* &= 103.5 \mu\text{sec} \\ U_{\min}^* &= 0.110 \text{ cm}/\mu\text{sec} \end{aligned} \quad (11)$$

as compared to DSM experimental values of

$$\begin{aligned} t_1 &= 103 \mu\text{sec} \\ U_{\min} &= 0.10 \text{ cm}/\mu\text{sec} \end{aligned} \quad (12)$$

It is appropriate at this point to recall that  $V_j^0$  can be calculated from the BASC code, thus the above calculation can be performed without knowledge of the experimental value of  $V_j^0$ .

Since the determination of  $x^*$  and  $y^*$  also results in the determination of the corresponding region of penetration, i.e.,  $Z_{c,i}$  corresponds to a region in  $x - y$  space, the penetration is also calculated - and required in the minimization of (9). The calculated penetration vs virtual stand-off distance is shown in Figure 1 along with the experimental values of the penetration depth. The agreement is excellent.

The minimization of (9) was accomplished by utilizing the "Complex Method" due to M. J. Box<sup>4</sup>. This method requires only function evaluations and not derivatives; thus the method is ideal for this particular application.

#### IV. VIRTUAL ORIGIN APPROXIMATION

In the above example, the penetration depth was given as a function of the virtual stand-off distance. In the DSM report, the authors obtained the location of the virtual origin from flash radiograph measurements; however, in many other reports, the virtual origin is either not given or is approximated by a "rule of thumb". For example, DiPersio, Jones, et al<sup>5</sup> use, from past experience, the rule "the

---

<sup>4</sup>M. J. Box, 'A New Method of Constrained Optimization and a Comparison with Other Methods,' *Computer J.*, 8, 43-52 (1965).

<sup>5</sup>P. DiPersio, W. Jones, A. Merendino, and J. Simon, 'Characteristics of Jet from Shell Girdler Shape Charges with Copper or Aluminum Liners,' *AD-70-1367*, September 1967 (UNCLASSIFIED). (AD #823839)

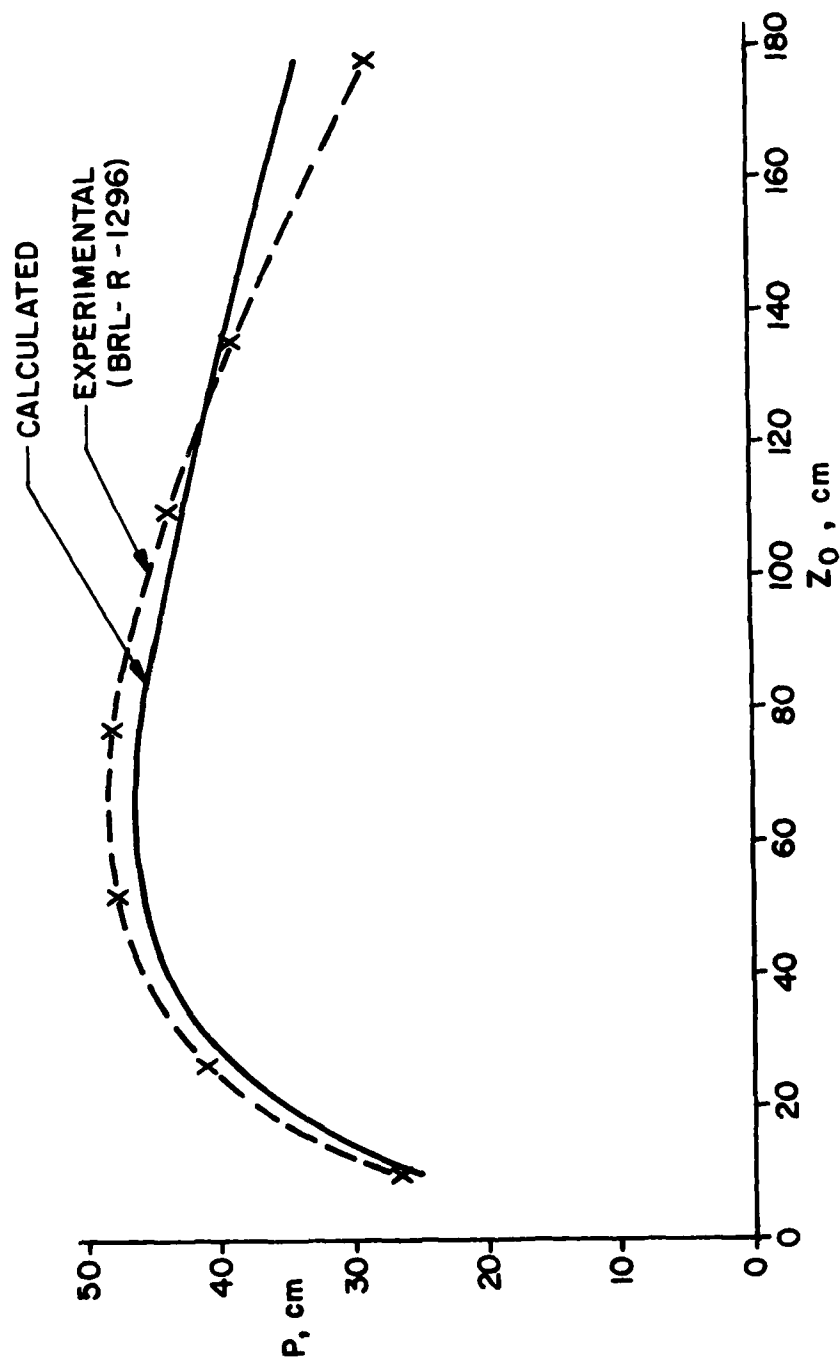


FIGURE 1. CALCULATED AND EXPERIMENTAL PENETRATION DEPTH VS  
STANDOFF DISTANCE FROM VIRTUAL ORIGIN FOR THE BRL  
PRECISION SHAPED CHARGE

approximate location of the virtual origin of a highly confined charge, ..., is three-fourths of the liner height ...". In attempting to determine  $t$  and  $U_{\min}$  from the data of reference 5, we found that the above rule did not result in adequate agreement between computed and experimental values. Therefore, we modified our computational procedures and let

$$Z_0 = B + S. \quad (13)$$

where  $B$  is the distance from the base of the liner, along the cone axis, to the apparent origin of the jet, and  $S$  is the stand-off distance. Thus equation (7) becomes

$$H(x, y, B) = \sum_{i=1}^N [P_{T,i}(S_i, B) - f(x, y, B, S_i)]^2 \quad (14)$$

so that we now seek  $x^*$ ,  $y^*$ , and  $B^*$  such that

$$H(x^*, y^*, B^*) \leq H(x, y, B).$$

Utilizing the penetration data of reference 5, equation (14) was minimized. In this minimization process, we constrained  $B$  to lie in the interval

$$0 \leq B \leq B_{\max}$$

where  $B_{\max}$  = height of cone + distance allowed for liner retainer ring ( $\approx 1.4$  cm). For the  $20^\circ$ ,  $60^\circ$ , and  $90^\circ$  conical liners, the resulting agreement of calculated and experimental jet break-up time was excellent. For the  $40^\circ$  copper liner, we found that if  $B_{\max}$  was taken to be twice the liner height, then good agreement could also be attained for this case. In Table 1, we present calculated break-up times  $t_1^*$  and observed values  $\hat{t}_1$ , calculated minimum penetration velocity  $U_{\min}^*$  and the calculated location of virtual origin  $B^*$ .

In obtaining the jet break-up times,  $t_1^*$ , listed in Table 1, we used, in each case, the corresponding experimental jet tip velocity reported in reference 5; however, it is noted again that the jet tip velocity can be calculated from the BASC code utilizing liner thickness,  $\epsilon$ , apex angle,  $\alpha$ , and explosive and liner material properties. In Table 2, we compare the BASC-code generated values with the experimental values for some of the 3.81 cm copper and aluminum liners of reference 5.

Table 1. Some Calculated and Observed Jet Data for  
the 3.81 cm Copper Liner Shaped Charge  
(asterisk denotes calculated value)

Cone Angle	$t_i^*$ , $\mu\text{sec}$	$\hat{t}_i$ , $\mu\text{sec}$	$U_{\min}^*$ , cm/ $\mu\text{sec}$	$B^*$ , cm
20°	41.5	40.8	0.18	12.2
40°	62.5	63.9	0.16	10.0
60°	65.3	66.7	0.14	4.4
90°	63.4	64.3	0.11	0.0

Table 2. Experimental and BASC-Code Generated Values of Jet Tip Velocity for Selected 3.81 cm Aluminum and Copper Liners

Cone Angle	Material	$\hat{V}_j^0$ , cm/ $\mu$ sec	$V_j^0$ , cm/ $\mu$ sec (BASC)
20°	Cu	0.99	1.03
20°	Al	1.12	1.08
40°	Cu	0.82	0.84
40°	Al	0.93	0.91
60°	Cu	0.67	0.74
60°	Al	0.81	0.82

In Figures 2-5, we have plotted the "best" penetration - virtual stand-off curves generated by minimizing (14) for each of the 3.8 cm (1.5") copper liners of reference 5. In each case, we used the average penetration values for each liner and we have plotted these average values, for comparison, on each figure. With the exception of the 20° liner, the agreement is satisfactory.

In Figure 6, we have plotted the computed "best" value  $B^*$  of the virtual origin location as a function of cone angle for the 3.81 cm copper liner and the 42° BRL precision shaped charge of reference 1. The plot indicates that the virtual origin location is approximately linear with respect to cone angle.

Finally, in Figure 7, we have plotted "best" values of  $U_{Min}^*$  as a function of cone angle for the 1.91 and 3.81 cm copper conical liners of reference 5. It appears that for the liner, explosive, and target complex of reference 5 that  $U_{Min}^*$  is approximately linear with respect to cone angle and does not depend greatly upon the cone base diameter for these scaled liners. Also, on Figure 7 we have plotted  $U_{Min}^*$  which was calculated from the penetration stand-off data of reference 1. We note that both the explosive and target properties have changed for this case.

#### V. DETERMINATION OF THE ENERGY CONSTANT

The hole volume produced by the penetrating jet can be calculated for each region of penetration by the equations (38), (40), and (42) of the DSM report. For example, for region 1\*

$$\tau_T = \xi \times \left\{ 1 - \left[ \frac{(1+y)y}{x} \right]^3 \right\}$$

where

$$\xi = \frac{\pi d_j^2}{24C} \rho_j (V_j^0)^2 \quad (15)$$

For each of the other regions, each equation is a function of  $\xi$ ,  $x$ ,  $z_0$ , and  $y$ . We have shown previously that  $x$  and  $y$ , i.e.,  $x^*$  and  $y^*$  can be obtained by minimizing (7) or (14), and have noted that  $d_j$  and  $V_j^0$  can be obtained from the BASC-code, thus if we denote the calculated hole volume, in its appropriate stand-off region by  $g(z_0, x^*, y^*, \xi)$  we obtain  $\xi^*$  by minimizing

$$G(\xi) = \sum_{i=1}^N \left[ \tau_T(z_{0,i}) - g(z_{0,i}, x^*, y^*, \xi) \right]^2 \quad (16)$$

\*See equations (2), (4), and (6) for corresponding boundary relations.

X : BRL - MR - 1866

— : CALCULATED

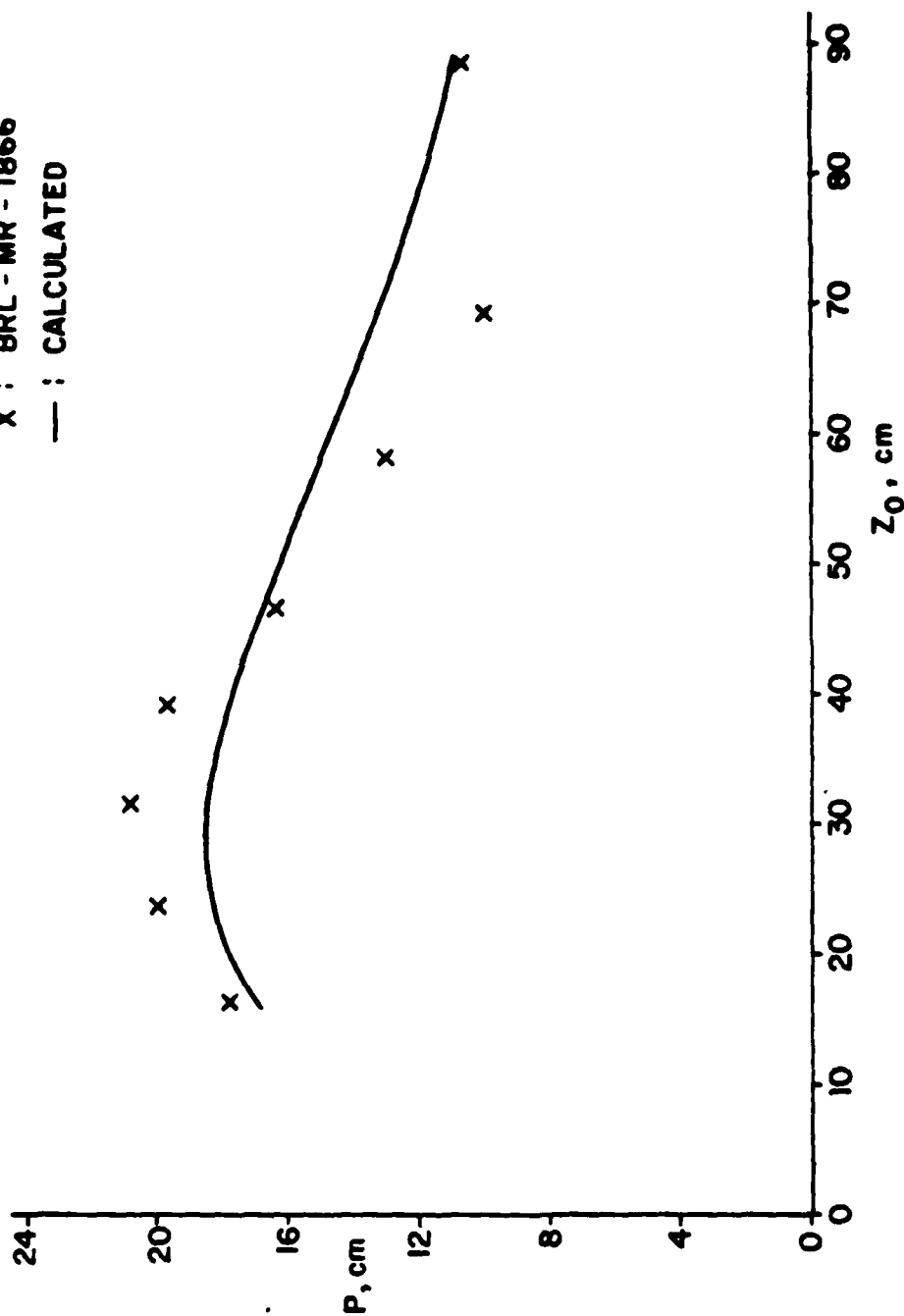


FIGURE 2. PENETRATION DEPTH VS VIRTUAL STANDOFF DISTANCE FOR THE  
3.81 CM., CU., CONICAL LINER. CONE ANGLE = 20° .

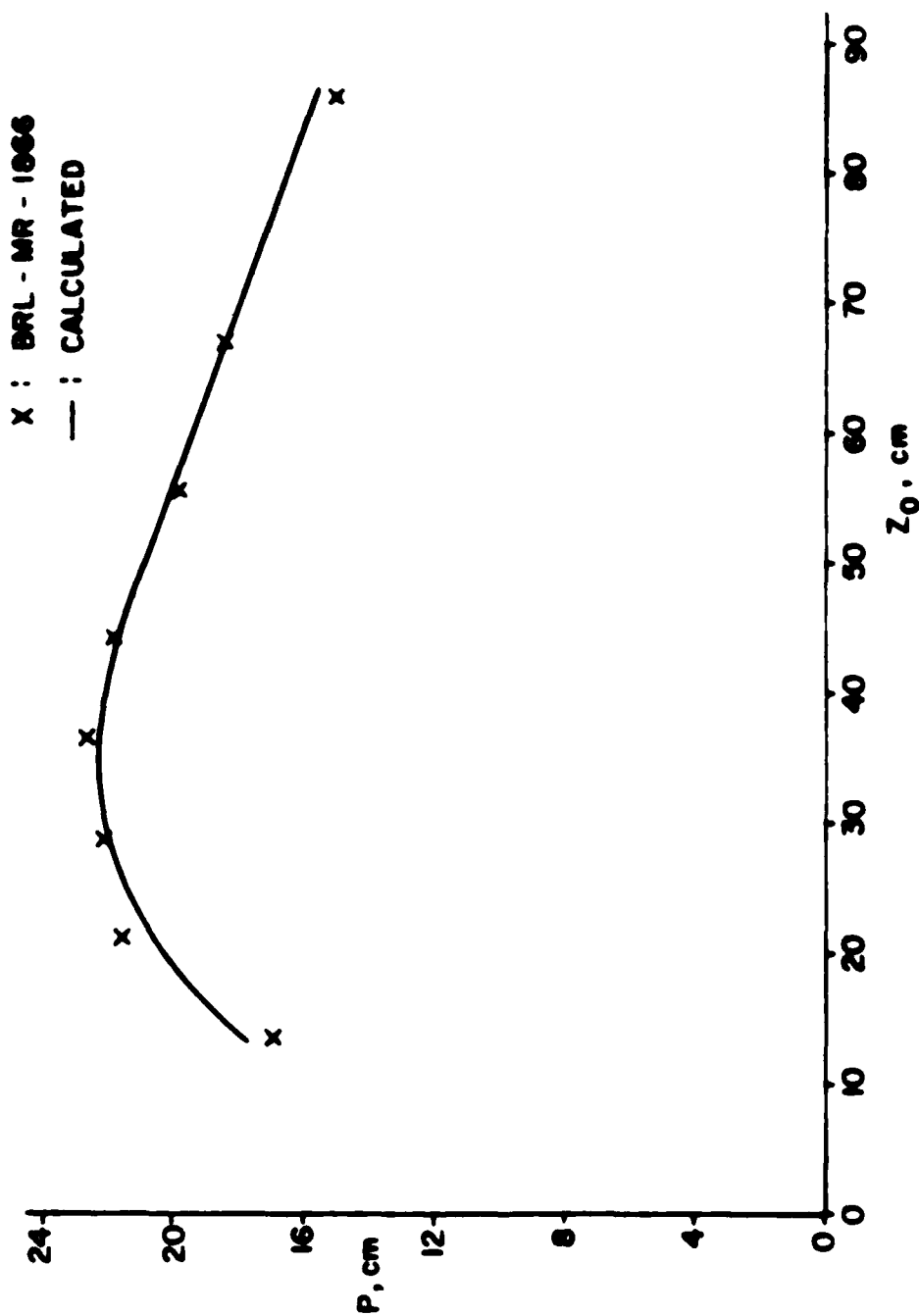


FIGURE 3. PENETRATION DEPTH VS VIRTUAL STANDOFF DISTANCE FOR THE  
 3.81 CM., CU., CONICAL LINER. CONE ANGLE =  $40^\circ$ .

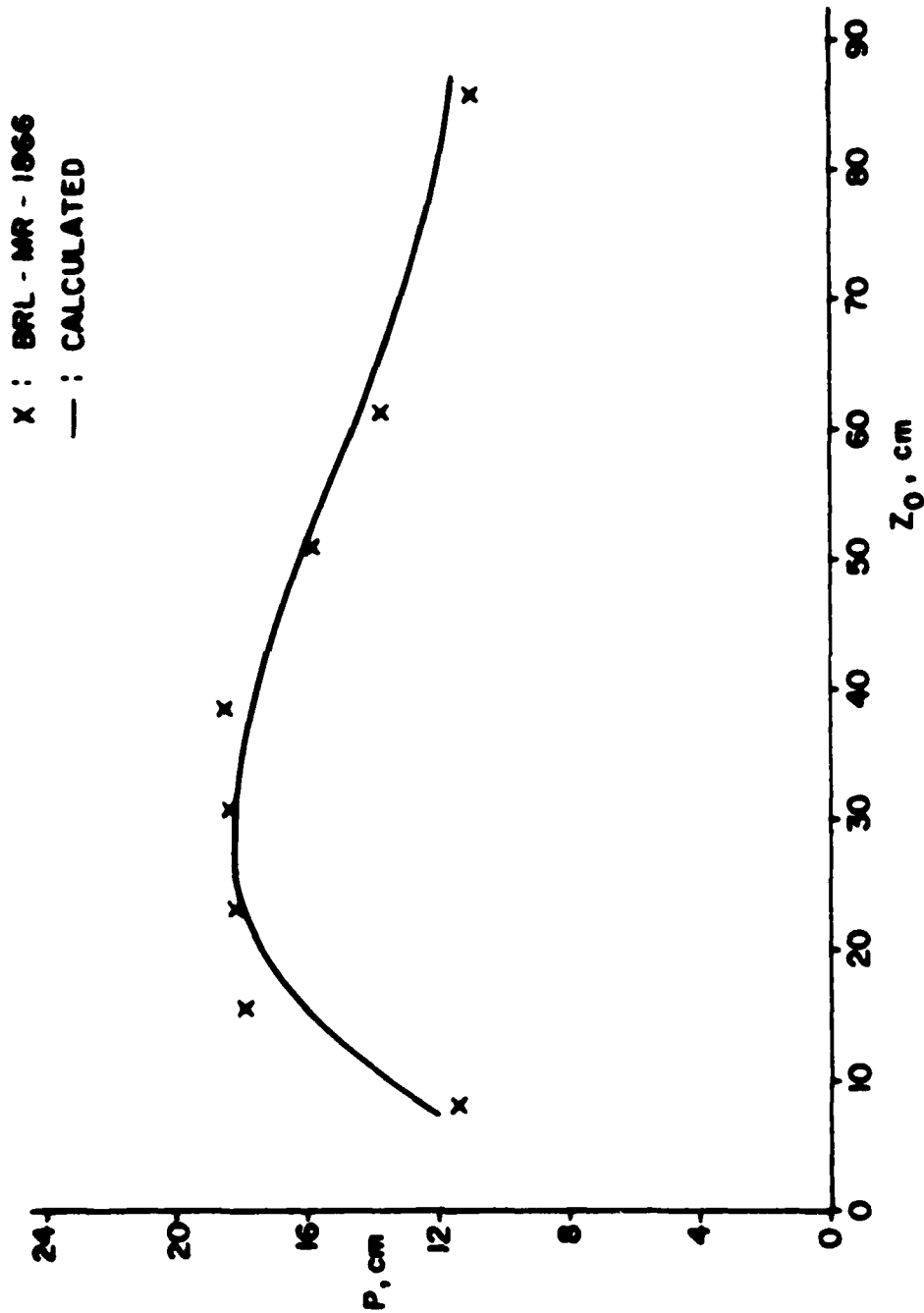


FIGURE 4. PENETRATION DEPTH VS VIRTUAL STANDOFF DISTANCE FOR THE 3.81 CM., CU., CONICAL LINER. CONE ANGLE =  $60^\circ$ .

X : BRL - MR - 1866  
 — : CALCULATED

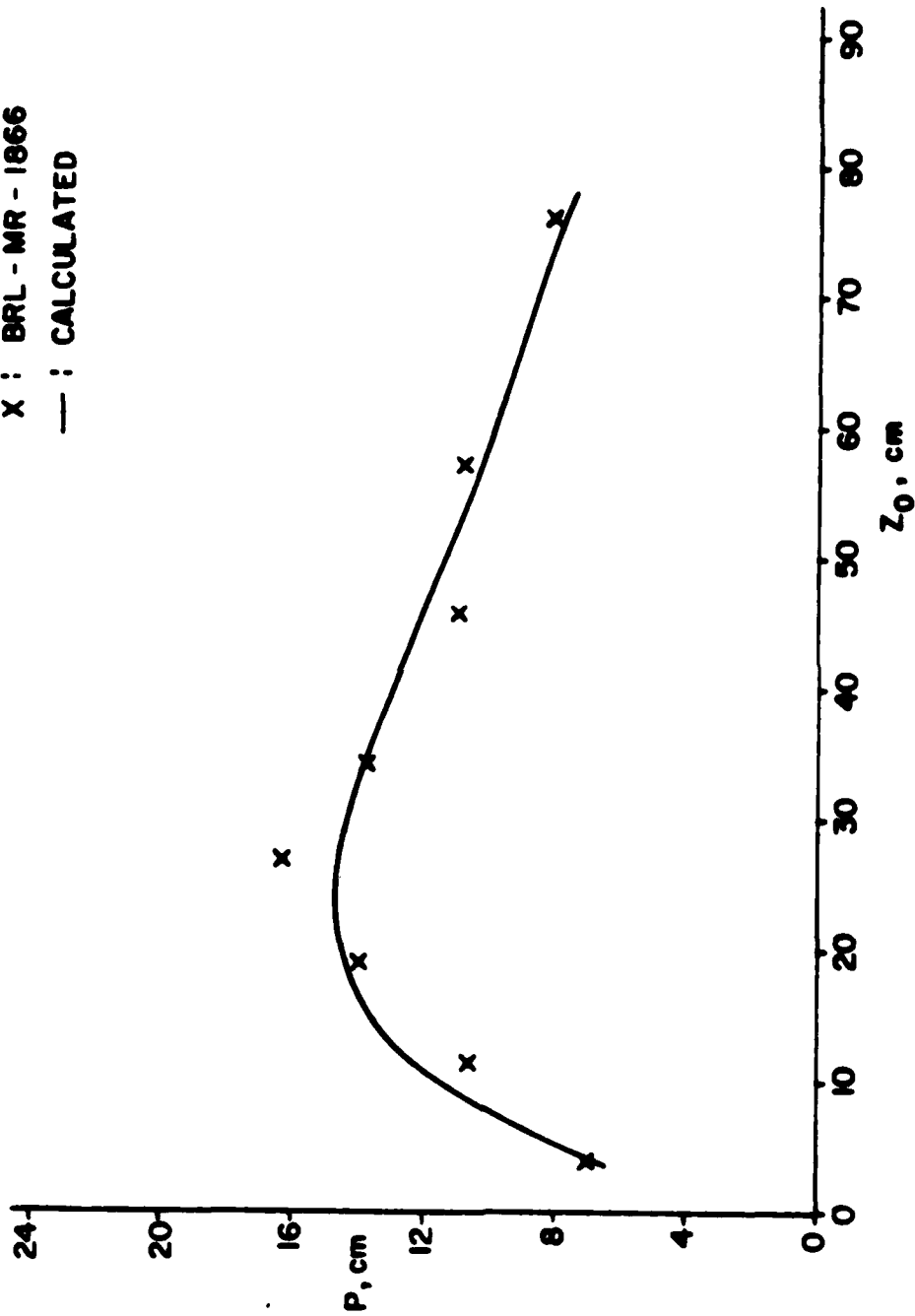


FIGURE 5. PENETRATION DEPTH VS VIRTUAL STANDOFF DISTANCE FOR THE  
 3.81 CM., CU., CONICAL LINER. CONE ANGLE =  $90^\circ$ .

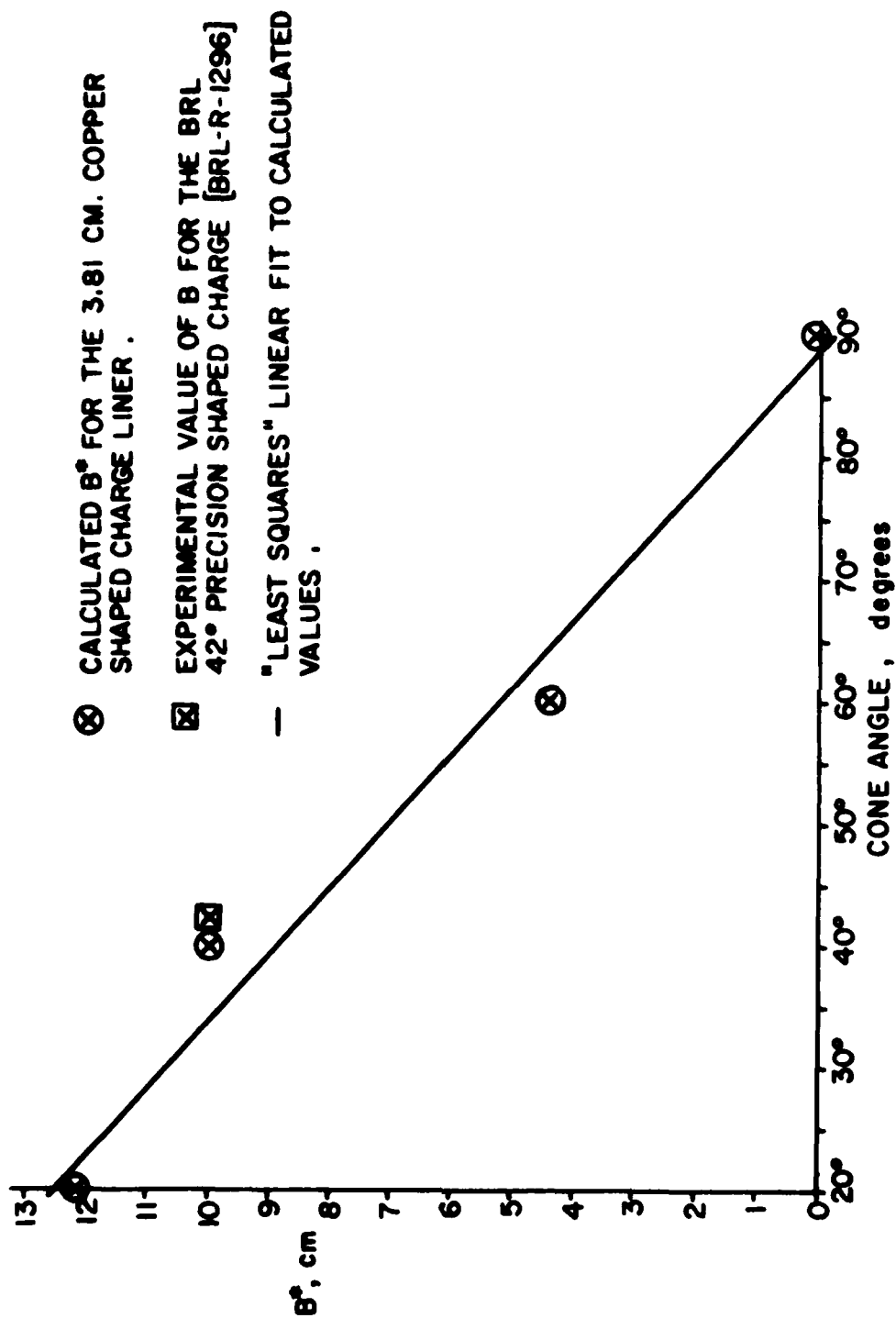


FIGURE 6. CALCULATED VIRTUAL ORIGIN VS CONE ANGLE .

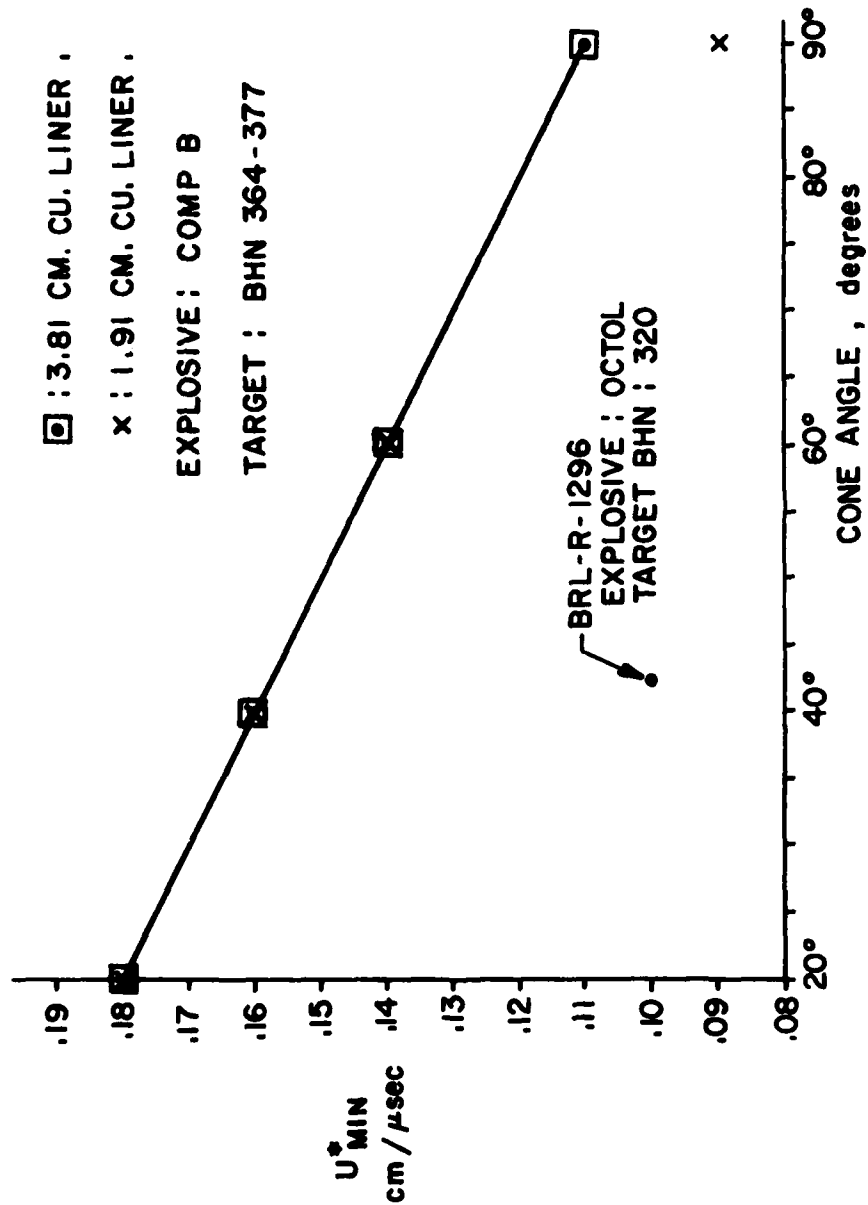


FIGURE 7. CALCULATED U<sub>MIN</sub> VS CONE ANGLE .

The value of  $\xi = \xi^*$  which minimizes (16) can then be used to determine the energy constant  $C$  whenever  $V_j^0$  and  $d_j$  are known. Since both  $d_j$  and  $V_j^0$  can be determined with BASC then a "best" value,  $C^*$ , of the energy constant can be determined.

## VI. SUMMARY

We have shown how penetration performance - stand-off data and hole volume - stand-off data can be utilized to determine values of specific functions of the DiPersio, Simon, Merendino shaped-charge parameters  $C$ ,  $U_{\min}$ , and  $t_1$ , and that specification of the initial jet tip velocity  $V_j^0$  determines "best" values of  $t_1$  and  $U_{\min}$ . If, in addition, the jet diameter  $d_j$  is known, then the energy constant  $C$  is readily determined. It is of interest to note that  $V_j^0$  and  $d_j$  are readily determined from Harrison's BASC code and are functions of the liner thickness and cone angle. The implication of this is that since  $x^*$  and  $y^*$  are determined from penetration performance data one may then search for "best" values of cone angle,  $\alpha$ , and liner thickness,  $\epsilon$ , which maximizes the jet break-up time  $t_1$ . From the definition of  $x$  we see that one should choose  $\alpha$  and  $\epsilon$  such that  $V_j^0$  is a minimum.

#### ACKNOWLEDGEMENTS

The authors thank Mr. R. Jameson, Dr. W. Walters, and Dr. M. Lampson of TBD for several helpful discussions.

# DISTRIBUTION LIST

No. of Copies	Organization	No. of Copies	Organization
12	Commander Defense Tech Info Ctr ATTN: DDC-DCR Ramses Station Alexandria, VA 22314	4	Commander US Army Armament Research and Development Command ATTN: DRDAR-TSS (2 cys) DRDAR-LCW DRDAR-SC Dover, NJ 07801
	Director Inst. for Def Analysis 440 Army-Navy Drive Arlington, VA 22202	1	Commander US Army Armament Materiel Readiness Command ATTN: DRDAR-LEP-L Tech Lib Rock Island, IL 61299
1	Director Defense Advanced Research Projects Agency 1400 Wilson Boulevard Arlington, VA 22209		Director US Army ARRADCOM Benet Weapons Laboratory ATTN: DRDAR-LCB-TL Wateroliet, NJ 12189
1	Director Def Intelligence Agency ATTN: DI-7B-3 Washington, DC 20301	1	Commander US Army Wateroliet Arsenal ATTN: SARWV-RDD-AT Wateroliet, NJ 12189
1	HQDA (DAMA-ADA-M) Washington, DC 20310	1	Commander US Army Aviation Research and Development Command ATTN: DRDAV-E 4300 Goodfellow Blvd. St. Louis, MO 63120
1	HQDA (DADA-DW) Washington, DC 20310	1	Commander US Army Air Mobility R&D Laboratory Ames Research Center Moffett Field, CA 94035
1	HQDA (DAMI) Washington, DC 20310		
1	Director US Army Engineer Water- ways Experiment Station P. O. Box 631 Vicksburg, MS 39106		
1	Commander US Army Materiel Development & Readiness Command ATTN: DRDMD-ST 5001 Eisenhower Avenue Alexandria, VA 22304		

# DISTRIBUTION LIST

No. of Copies	Organization	No. of Copies	Organization
1	Director Applied Technology Lab US Army Research & Technology Labs (AVRADCOM) ATTN: DAVDL-EU-SY-RPV Fort Eustis, VA 23604	1	Commander US Army Missile Command ATTN: DRSMI-YDL Redstone Arsenal, AL 35809
1	Commander US Army Troop Support and Aviation Materiel Readiness Command ATTN: DRSTS-G 4300 Goodfellow Boulevard St. Louis, MO 63166	1	Commander US Army Mobility Equipment R&D Command ATTN: DRDME-WC Fort Belvoir, VA 22060
1	Commander US Army Communications R&D Command ATTN: DRDCO-PPA-SA Fort Monmouth, NJ 07703	1	Commander US Army Natick Research and Development Comd ATTN: DRDNA-VCA, Mr. L. Flores Natick, MA 07162
1	Commander US Army Communications Command ATTN: ATSI-CD-MD Fort Huachuca, AZ 85613	1	Commander US Army Tank Automotive R&D Command ATTN: DRDTA-UL Warren, MI 48090
1	Commander US Army Electronics R&D Command Tech Support Activity ATTN: DELSD-L Fort Monmouth, NJ 07703	1	President US Army Airborne, Electronics & Special Warfare Board Fort Brass, NC 28307
1	Commander US Army Missile Command ATTN: DRSMI-R Redstone Arsenal, AL 35809	1	President US Army Armor & Engineer Board Fort Knox, KY 40121
		1	President US Army Artillery Board Fort Sill, OK 73504
		1	President US Army Infantry Board Fort Benning, GA 21905

# DISTRIBUTION LIST

No. of Copies	Organization	No. of Copies	Organization
1	Project Manager DARCOM Patriot Project Office Redstone Arsenal, AL 35809	1	Commander US Army TRADOC Systems Analysis Activity ATTN: ATAA-SL, Tech Lib White Sands Missile Range NM 88002
1	Project Manager XM-1 Tank System 28150 Dequindre Street Warren, MI 48092	1	Commander US Army John F. Kennedy Center for Military Assistance ATTN: Special Ops Agency Fort Brass, NC 28307
1	Project Manager DIVADS Gun US Army Armament R&D Command ATTN: DRCPM-ADG Dover, NJ 07801	2	Commandant US Army Armor School ATTN: Armor Agency ATSB-CD-MM Fort Knox, KY 40121
1	Project Manager, ARTADS US Army Electronics R&D Command ATTN: DRCPM-TDS-CEN Fort Monmouth, NJ 07703	1	Commandant US Army Artillery School Fort Sill, OK, 73503
1	Office of the Project Manager Navigation/ Control Systems US Army Electronics R&D Command ATTN: DRCPM-NC Fort Monmouth, NJ 07703	1	Commandant US Army Aviation School ATTN: Aviation Agency Fort Rucker, AL 36362
1	Commander US Army Materials and Mechanics Research Ctr ATTN: E. DeLuca Watertown, MA 02172	1	Commandant US Army Engineer School ATTN: ATSE-CD Library Fort Belvoir, VA 22060
1	Commander US Army Trainings and Doctrine Command Fort Monroe, VA 23651	1	Commandant US Army Infantry School ATTN: ATSH-I-MS-F Fort Benning, GA 31905

# DISTRIBUTION LIST

No. of Copies	Organization	No. of Copies	Organization
1	Commandant US Army Infantry School ATTN: Infantry Agency Fort Benning, GA 31905	3	Commander Naval Weapons Center ATTN: Code 31804 Code 3835 Code 338 China Lake, CA 93555
1	Commandant US Army Intelligence Sch ATTN: Intel Ascy Fort Huachuca, AZ 85613	1	Commander Naval Research Lab Washington, DC 20375
2	Chief of Naval Operations ATTN: OP-721 OP-351G Department of the Navy Washington, DC 20350	2	Commander David Taylor Naval Ships Research & Development Center ATTN: Mr. H. Wolk Tech Library Bethesda, MD 20084
1	Chief of Naval Materiel ATTN: MAT-0324 Department of the Navy Washington, DC 20360	1	Commandant US Marine Corps ATTN: AAW-1B Washington, DC 20380
2	Commander Naval Air Systems Command ATTN: WEPS, Mr. R. Sawyer AIR-604 Washington, DC 20360	1	Commandant US Marine Corps ATTN: POM Washington, DC 20380
1	Commander Naval Ordnance Systems Command Washington, DC 20360	1	Commanding General Fleet Marine Force, Atlantic ATTN: G-4 (NSAP) Norfolk, Va 23511
1	Commander Naval Air Development Center, Johnsville ATTN: Code SRS Warminster, PA 18974	1	Commander Marine Corps Development and Education Command (MCDEC) Quantico, VA 22134
2	Commander Naval Surface Weapons Ctr ATTN: DX-21, Lib Br. Mr. N. Ruppert Dahlgren, VA 22448	1	HQ USAF/SAMI Washington, DC 20330

# DISTRIBUTION LIST

No. of Copies	Organization	No. of Copies	Organization
3	AFSC (SCFO; SDW; DLCAW) Andrews AFB, MD 20331	1	Shock Hydrodynamics ATTN: Dr. L. Zernow 4710-16 Vineland Ave North Hollywood, CA 91602
2	ADTC (DODL; ADRL-2) Eglin AFB, FL 32542	2	Southwest Research Inst Dept of Mech Sciences ATTN: Mr. A. Wenzel Dr. W. E. Baker P.O. Drawer 28510 San Antonio, TX 78284
1	AFATL (SLYW) Eglin AFB, FL 32542	1	Physics International 2700 Marced St San Leandro, CA 94577
1	PSO Field Office P.O. Box 1925 Eglin AFB, FL 32542	1	Rockwell International Missile Systems Div P. O. Box 1259 Columbus, OH 43216
1	TAWC Eglin AFB, FL 32542		
	TAC (INAT) Langley AFB, VA 23065		
1	SAC Offutt AFB, NE 68113		
1	AFWA /FIBO Wright-Patterson AFB, OH 45433		
1	FTD (ETD) Wright-Patterson AFB, OH 45433		
1	USAFB (OPB) AFD New York 09012		
1	Dept. Of State Office Of Security 21st and C Street Washington, DC 20520		
1	Cattelle Columbus Laboratories ATTN: Ordnance Div 505 King Avenue Columbus, OH 43201		
			Aberdeen Proving Ground
		4	Dir, USAMSAA ATTN: DRXSY-R Mr. K. Myers DRXSY-MF Mr. H. Cohen DRXSY-R Mr. R. Simmons DRXSY-A Mr. D. O'Neill
		1	Cdr, USATECOM ATTN: DRSTE-TN-F
		1	Dir, USACSL BLDG. E3516, EA ATTN: DRDAR-CLB-PA

### USER EVALUATION OF REPORT

Please take a few minutes to answer the questions below; tear out this sheet, fold as indicated, staple or tape closed, and place in the mail. Your comments will provide us with information for improving future reports.

1. BRL Report Number \_\_\_\_\_

2. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which report will be used.)  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

3. How, specifically, is the report being used? (Information source, design data or procedure, management procedure, source of ideas, etc.) \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

4. Has the information in this report led to any quantitative savings as far as man-hours/contract dollars saved, operating costs avoided, efficiencies achieved, etc.? If so, please elaborate.  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

5. General Comments (Indicate what you think should be changed to make this report and future reports of this type more responsive to your needs, more usable, improve readability, etc.) \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

6. If you would like to be contacted by the personnel who prepared this report to raise specific questions or discuss the topic, please fill in the following information.

Name: \_\_\_\_\_

Telephone Number: \_\_\_\_\_

Organization Address: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_